Office de la propriété intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An Agency of Industry Canada

MARKS & CLERK
Box 957
Station B
OTTAWA Ontario
K1P 5S7

Date : 2000/12/18

FILING CERTIFICATE

Application No.	: **2,325,362**	**Filing Date**	: 2000/11/08
Expected Laid-Open Date	: 2002/05/08	**Your Reference**	: 10207-5

Title of Invention : METHOD AND APPARATUS FOR HIGH-ENERGY GENERATION AND FOR INDUCING NUCLEAR REACTIONS

Applicant(s) : THE UNIVERSITY OF MICHIGAN

Inventor(s) : MAKSIMCHUK, ANATOLY; NEMOTO, KOSHICHI; FLIPPO, KIRK; GU, SHAOTING; BANERJEE, SUDEEP; UMSTADTER, DONALD; MOUROU, GERARD; BYCHENKOV, VALERY; NAYUKI, TAKUYA

Special Notice

You are reminded that annual fees to maintain your application are needed for each one-year period between the 2nd and 20th anniversaries and must be paid on or before each anniversary. Failure to pay within the prescribed time limit will lead to abandonment of your application.

Commissioner of Patents

Office de la Propriété Intell ctu lle du Canada

Un organisme d'Industrie Canada

Canadian Int ll ctual Property Office

An agency of Industry Canada

CA 2325362 A1 2002/05/08

(21) 2 325 362

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) Date de dépôt/Filing Date: 2000/11/08

(41) Mise à la disp. pub./Open to Public Insp.: 2002/05/08

(51) Cl.Int.^{7}/Int.Cl.^{7} G21B 1/00

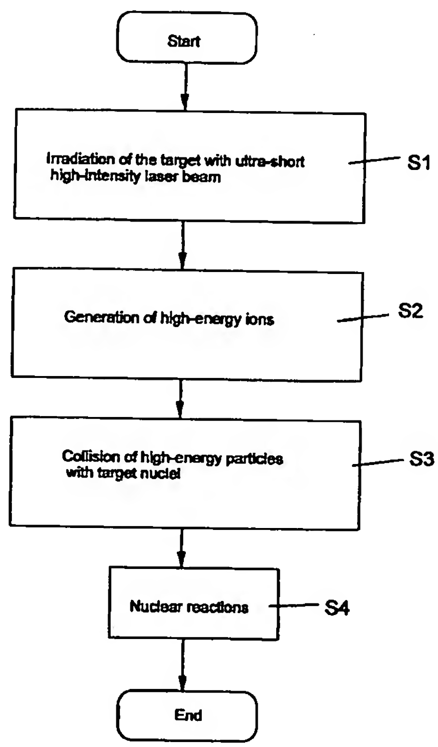
(71) Demandeur/Applicant:
THE UNIVERSITY OF MICHIGAN, ZZ

(72) Inventeurs/Inventors:
MAKSIMCHUK, ANATOLY, US;
NEMOTO, KOSHICHI, JP;
FLIPPO, KIRK, US;
GU, SHAOTING, US;
BANERJEE, SUDEEP, US;
UMSTADTER, DONALD, US;
MOUROU, GERARD, US;
BYCHENKOV, VALERY, US;
NAYUKI, TAKUYA, JP

(74) Agent: MARKS & CLERK

(54) Titre : METHODE ET APPAREIL POUR PRODUIRE DES PARTICULES DE HAUTE ENERGIE ET AMORCER DES REACTIONS NUCLEAIRES

(54) Title: METHOD AND APPARATUS FOR HIGH-ENERGY GENERATION AND FOR INDUCING NUCLEAR REACTIONS



(57) Abrégé/Abstract:
The present invention is directed to methods for generation of high-energy particles. The invention is further directed to methods for causing nuclear transformations. Furthermore, the invention pertains to reaction devices capable for generation of such high-energy particles and initiation of such nuclear transformations. Even more particularly, the present invention is directed to such methods an devices and their application and integration into medical diagnostic procedures including, but not limited to, positron emission tomography. Finally, the present invention is directed to such methods and devices and their use and integration into material inspection, nuclear transformation and/or nuclear reaction simulation.

METHOD AND APPARATUS FOR HIGH-ENERGY GENERATION AND FOR INDUCING NUCLEAR REACTIONS

The present invention is directed to methods for generation of high-energy particles. The invention is further directed to methods for causing nuclear transformations. Furthermore, the invention pertains to reaction devices capable for generation of such high-energy particles and initiation of such nuclear transformations. Even more particularly, the present invention is directed to such methods an devices and their application and integration into medical diagnostic procedures including, but not limited to, positron emission tomography. Finally, the present invention is directed to such methods and devices and their use and integration into material inspection, nuclear transformation and/or nuclear reaction simulation.

OUTLINE FOR DETAILED DISCLOSURE

A. Description of the Invention:

1. Abstract of Invention

The present invention provides method and apparatus to produce a collimated beam of high-energy ions by focusing an intense, short duration laser pulse onto a target. These high-energy ions are then used to produce nuclear reactions in the same target or in another target placed behind the laser target.

2. Claims

1. The method to produce a collimated beam of high-energy ions by focusing an intense, short duration laser pulse onto a target.
2. The method according to claim 1 wherein said collimated beam of high-energy ions is accelerated in the laser direction and normal to the target surface.
3. The method according to claim 1 wherein the energy of ions exceeds 100 keV.
4. The method according to claim 1 wherein the duration of ion pulse is shorter than 10^{-9} seconds.
5. The method according to claim 1 wherein said laser pulse has the intensity greater than 10^{18} W/cm^2.
6. The method according to claim 1 wherein said laser pulse has the duration less than 10^{-11} seconds.
7. The method according to claim 1 wherein said laser pulse has a repetition rate above 10^{-3} Hz.
8. The method according to claim 1 wherein said target element is a solid.
9. The method according to claim 1 wherein said target element is a liquid jet.
10. Th method according to claim 1 wherein said target element is a droplet jet.
11. The method of inducing nuclear reactions with high-energy ions generated according to Claims 1-10 by irradiation of targets with said ions.
12. The method of inducing nuclear reactions in Claim 11 by use the same target for laser irradiation and for generation of high-energy ions. (note: Nuclear reactions are induced inside a laser target itself.)
13. The method of inducing nuclear reactions in Claim 11 by use different targets for laser irradiation and for generation of high-energy ions. (note: Nuclear reactions are induced in another target neighboring a laser target.)
14. The method of inducing nuclear reactions in one of the Claims 12 and 13 using above mentioned high-energy ions which are protons or deuterons or tritons, and are irradiated on to above mentioned targets and induce nuclear fusion reactions.
15. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{11}B(p,n)^{11}C by irradiating protons as above mentioned high-energy ions onto targets which contain boron-11.
16. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{10}B(d,n)^{11}C by irradiating deuterons as above mentioned high-energy ions onto targets which contain boron-10.
17. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{10}B(p,alpha)^{7}Be by irradiating protons as above mentioned high-energy ions onto targets which contain boron-10.
18. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{1}2C(d,n)^{13}N by irradiating deuterons as above mentioned high-energy ions onto targets which contain carbon-12.
19. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{14}N(p,alpha)^{11}C by irradiating protons as above mentioned high-energy ions onto targets which contain nitrogen-14.
20. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{16}O(p,alpha)^{13}N by irradiating protons as above mentioned high-energy ions onto targets which contain oxygen-16.
21. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{14}N(d,n)^{15}O by irradiating deuterons as above mentioned high-energy ions onto targets which contain nitrogen-14.
22. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{15}N(p,n)^{15}O by irradiating protons as above mentioned high-energy ions onto targets which contain nitrogen-15.
23. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{20}Ne(d,alpha)^{18}F by irradiating deuterons as above mentioned high-energy ions onto targets which contain neon-20.
24. The method of inducing nuclear reactions in Claim 14 inducing nuclear fusion reaction ^{18}O(p,n)^{18}F by irradiating protons as above mentioned high-energy ions onto targets which contain oxygen-18.

25. The method of inducing nuclear reactions in Claims from 11 to 24, by irradiating repetitively above mentioned laser pulse with pulse interval shorter then half lifetimes of isotopes produced by nuclear reactions.
26. The method of inducing nuclear reactions in Claims from 11 to 24 with excited atomic nuclei contained in high-energy ions generated from the laser-irradiated target.
27. The apparatus for high-energy ion generation and for inducing nuclear reactions, which contains a high-intensity short pulse laser, laser delivery and focusing system, laser irradiated targets which are the source of high-energy ions, and targets containing nuclei which participate in nuclear reactions.

DETAILED DESCRIPTION OF THE INVENTION

1. THE TECHNOLOGY CATEGORY TO WHICH THE INVENTION BELONGS.
This invention concerns with methods and apparatus for generation of high-energy ions and for inducing nuclear reactions using high-intensity short laser pulses. This invention is related to ion accelerators and can be used in medicine for radiation therapy and medical radioisotope production, material diagnostic, diagnostic of equipment and facilities, other nuclear transmutation, nuclear reaction simulator.

2. THE PREVIOUS TECHNOLOGY
Since their invention more than sixty years ago cyclotrons (and linear accelerators) have been the standard method used to accelerate protons and ions for applications in nuclear medicine and for radioisotope production.

3. THE SUBJECT WHICH THIS INVENTION CAN SOLVE.
The above-mentioned methods for high-energy ion generation and isotope production need expensive and large-scale equipment, that limits their use. Because of the short pulse duration and, a high-intensity laser based ion accelerator can provide a peak current 3 to 4 order of magnitude higher, that a conventional technology. Such high ion current can be beneficial for cancer hadron therapy because of the possible decrease in absorbed radiation dose for cancer treatment.

4. PURPOSE OF THE INVENTION
The purpose of this invention is to realize the method and apparatus for high-current high-gradient ion acceleration and for inducing nuclear reactions on a tabletop.

5. THE METHOD AND APPARATUS FOR SOLVING THE ABOVE-MENTIONED SUBJECT.

The present invention provides a method and apparatus produce energetic ions from plasmas by focusing an intense, short duration optical pulse from a laser onto a target. The concentrated energy contained in the focused laser beam ionizes the target material, raising it to temperature for production of plasma consisting of free electrons and ions. The electrons in the target material are expelled and accelerated from a small focusing area with high energies by very strong electro-magnetic fields or light pressure of the laser pulse or traveling plasma waves induced by laser pulse or stimulated scattering of the laser pulse. After expulsion of electrons, ions are left because of large inertia of ions and thus the charge separation is produced. Ions are accelerated by electric fields caused by this charge separation as well as own uncompensated charge. This charge separation is sustained, until electrons coming from the surrounding areas neutralize it. The direction of the high-energy ion emission is usually limited within some angle around the normal direction of the target surface, simplifying the usage of these high-energy ion beams. The acceleration length is 5 to 6 orders of magnitude shorter than in conventional accelerators because of enormously large acceleration electric field exceeding 10 GeV/cm. High-energy ions s are generated only during very short periods after the laser irradiation. The number of ion accelerated exceed 10^{10} particles, providing a peak current of few kiloampers, which is 3 to 4 magnitude higher than the conventional accelerators can produce. These high-energy ions are then used for inducing of nuclear reactions, namely the production of positron active isotopes, in the same laser target or in other target placed behind the laser target. This invemtion has another advantage compare to conventional accelerators. Because of the small acceleration region of laser-produced plasma (less than 1 mm) the radiation shielding area can be much smaller than in conventional accelerators.

6. EXAMPLE OF THIS INVENTION

An example will be described in the following section using the picture showing a schematic diagram of this invention.

6.1. Figure 1 and 2 shows the method and the apparatus for high-energy ion acceleration and for inducing nuclear reactions on the basis of this invention, respectively. This apparatus contains (1) the irradiation target 11, (2) and a laser and laser irradiation equipment 12, (3) and a target 13 containing nuclei, which cause nuclear reaction with high-energy ions 19. The laser beam 18, which is focused onto target 11, has intensity greater than 10^{18} W/cm^2 and pulse duration shorter than 10 picosecond. The laser beam ionizes the target material, generates high-energy electrons and which are due to charge separation accelerate ions 19 to high energies.

6.2. An irradiation target is a thin film for example, in more details a Mylar film14 coated with deuterated plastic layer 15 as an example. The thickness of film 14 is about 10 micrometer as an example.

6.3. A laser and laser irradiation equipment 12 are the hybrid Ti:Al_2O_3/Nd:phosphate glass CPA laser with 10 TW as an example. For example, this laser can emit a laser beam 1 8 with 0.4 ps pulse duration and about energy of 3 J. This laser beam can be irradiated on to the deuterated plastic layer 15 on the irradiation target 11 with focusing diameter of 10 micrometer. This laser stretches laser pulses emitted from a oscillator by a pulse stretcher at first, next amplifies these stretched pulses by amplifiers, finally increases peak intensity by compressing pulse duration by a pulse compressor. Then, this ultra-short pulse with high peak intensity is focused by a focusing optics, and is irradiated onto a deuterated plastic layer 15 on an irradiation target 11. For example, first an oscillator pulse with pulse duration of 0.1 picosecond and energy of 1 microjoule is stretched to a pulse of 1 nanosecond in duration by a pulse stretcher, next the pulse is amplified to a pulse of 1 nanosecond in duration and with energy of about 1 J, finally the pulse is compressed to a short pulse with duration of 0.1 picosecond and energy of about 1 J. Thus, compression of pulse can increase the peak intensity of laser beam 18 up to 100 TW.

6.4. A target 13 is a pellet of enriched boron 10 up to about 90% in concentration as an example. A target 13 is installed at 8 mm behind an irradiation target11 irradiated by a laser beam18 as an example.

6.5. A filter 16 made of Polyethylene Terephthalate and a monitor 17 is installed behind a target13. A filter 16 and a monitor 17 are means to estimate energy of high-energy particles 19, which are irradiated onto a target 13. There is a relation between thickness of a filter16 and energy of particles, which can penetrate the filter 16. Therefore, we can know that the particle energy is higher than the energy necessary to penetrate the filter 16 when particles are detected by the monitor 17 behind the filter 16. For example, energy of about 1 MeV is necessary for proton to penetrate the filter 16 with 10 micrometer in thickness. Therefore, when the monitor 17 detects protons, we can know that the protons have higher energy than 1 MeV. However, the filter 16 and the monitor 17 are not necessary to induce nuclear reaction and can be omitted.

6.6. Since the apparatus for inducing nuclear reaction can be surrounded by shields which are not shown in the picture, high-energy particles generated by irradiation of laser beam18 onto an irradiation target 11 and radiation from productions of nuclear reaction can be shielded.

6.7.Next, the method of inducing nuclear reaction is described. In this methods, first a laser beam 18 which can ionize an irradiation target 11 is irradiated onto an irradiation target 11 (step 1), second high energy particles 19 are generated (step 2), third these high energy particles collide with a target 13 (step 3), and fourth nuclear reactions are induced (step 4).

6.8. A laser beam with duration shorter than 10 picosecond (10^{-11} s) is adequate to use for laser beam 18. When laser pulse duration is longer than 10 picosecond, the diffusion of ions produced by laser beam 18 starts before the end of laser beam because of long pulse duration of laser beam 18. Therefore, charge separation area can not grow large enough for acceleration of ions up to high energy. Shorter pulse duration can make higher intensity and therefore higher electric field of laser beam 18 even though the energy is the same, and thus shorter pulse can make larger charge separation.

6.9. Electrons are expelled and accelerated from a small irradiation area by high electric field or light pressure of the laser beam 18, or traveling plasma wav generated by the high-intensity laser pulse (step 1).

6.10. On the other hand, ionized ions can not move for a while after the end of laser beam pulse 18 because of their heavier mass than electrons. Therefore, the small irradiation region contains dense ions, next the ions are accelerated like an explos.. n by the static electric field, and finally ions can be accelerated high energy up to 10 MeV as shown in Fig.3 as n example (step2). Thus, positive ions can be generated as high-energy particles 19 by irradiation of laser beam .8 onto irradiation target 11. However, it is not always necessary to accelerate high-energy particles 19 up to 10 MeV. For example, 100 keV, is sufficient for some reactions. It is enough to accelerate particles to the energy level with enough cross section for nuclear reactions.

6.11. Here, the area of region irradiated by the laser beam18 is finite, therefore diameter and thickness of dense area of positive ions are few 10 micrometers and less than 10 micrometers, so the ion-dense region is sheet-like. Then, one directional electric field can be produced. Therefore, ions accelerated by this electric field are emitted to the direction normal to the surface irradiated by laser beam 18 and away from a laser, in other words, the direction to the target 13 behind the irradiation target 11. In the real experiment, ion beam, which is the stream of positive ions, are emitted with the full corn angle of 40 degrees.

6.12. In this example, a high-energy ion is deuteron because the deuterated plastic layer 15 on the irradiation target 11 is irradiated by the laser beam 18. Thus, deuteron can be generated as a high-energy particle by irradiation of the laser beam 18 onto the irradiation target 11. These high-energy deuterons collide with the target 13 made of boron (step 3). Therefore, inside the target 13, nuclear reaction $^{10}B(d,n)^{11}C$ can be induced (step4). Because of this, carbon-11 (^{11}C) and neutron (n) can be produced. Usually, nuclear reactions are induced in the region 13a from the surface of the target 13 to the depth of 1mm. Therefore, the produced carbon-11 absolutely remains inside the target 13.

6.13. The dueterated plastic layer can be omitted from the target 11, and normal boron without enrichment of boron-10 can be used as the target 13. In this case, proton is mainly generated as high-energy particle. Protons can be generated as high-energy particles 19 by irradiation of the laser beam 18 on to the irradiation target 11. The nuclear reaction $^{11}B(p,n)^{11}C$ can be induced when these high energy protons collide with the target 13. Therefore, carbon-11 and neutrons can be produced.

6.14. Carbon-11 is a pure positron emitter with half lifetime of 20 minutes and can be used for diagnostics in medicine and defect diagnostics for materials. Carbon-11 has advantages of easier management as nuclear material compared with natrium-22 because radio activity of carbon-11 decay so much even in one night because of short half lifetime of 20 minutes. Carbon-11 of 2 nanoCurie can be produced by one pulse of laser beam18 with above mentioned laser energy. Carbon-11 of 10 micro Curie can be produced when the laser beam18 is irradiated with 10 Hz pulse repetition rate for 1 hour. This radioactivity is the same level as the commercial natrium-22 as a calibration source.

6.15. The electrons expelled and accelerated from the region irradiated by the laser beam 18 have high energy, and they generate high energy x-rays by bremsstrahlung during going through the target 11 and other materials. This x-rays are emitted to the direction normal to the surface irradiated by the laser beam 18 and away from the laser and laser irradiation equipment 12.

6.16. The generated x-rays with energy higher than 1.02 MeV can produce a pair of a electron and a positron through interaction with the target 11 and other materials. Therefore, high-energy positrons and electrons can be generated. Electrons, x-rays (electromagnetic wave) and positrons can be generated as high-energy particles by irradiating the laser beam 18 on to the irradiation target 11.

6.17. On the other hand, high-energy positive ions generated by irradiation of the laser beam 18 can induce nuclear fusion or nuclear fission with other materials inside the irradiation target 11. And the nuclear reactions such as (gamma, n) can be induced by gamma-rays generated from the above-mentioned nuclear reactions and isotopes and neutrons can be produced.

6.18. Many reactions other than above mentioned $^{10}B(b,n)^{11}C$ and $^{11}B(p,n)^{11}C$ by changing the combination of the materials of the irradiation target 11 and the target 13. For example, by using material containing hydrogen for the irradiation target 11, protons (p) can be mainly generated as the high energy positiv ions. Therefore, by colliding these high energy protons with the target 13 containing nitrogen-14, the nuclear fusion $^{14}N(p,alpha)^{11}C$ can be induced, and carbon-11 which is a radioisotope with short half lifetime and alpha particles can be

produced. And, by colliding protons as high energy particles 19 with the target 13 containing oxygen-16, the nuclear fusion $^{16}O(p,alpha)^{13}N$ can be induced, and nitrogen-13, which is a radioisotope with short half lifetime, and alpha particles can be produced. Moreover, by colliding protons as high energy particles19 with the target13 containing oxygen-18, the nuclear fusion $^{18}O(p,n)^{18}F$ can be induced, and fluorine-18 which is a radioisotope with short lifetime and neutrons can be produced. Moreover, by colliding protons as high energy particles with the target 13 containing boron-10, the nuclear fusion $^{10}B(p,alpha)^{7}Be$ can be induced, and Beryllium-7 which is a radioisotope with short half lifetime and alpha particles can be produced. And, by colliding protons as high energy particles 19 with the target 13 containing nitrogen-15, the nuclear fusion $^{15}N(p,n)^{15}O$ can be induced, and oxygen-15 which is a radioisotope with short half lifetime and neutron can be produced.

6.19. And by using an irradiation target containing deuterium, deuterons (d) are mainly generated as high energy positive ions. Therefore, by colliding these high energy deuterons with the target containing carbon-12, the nuclear fusion $^{12}C(d,n)^{13}N$ can be induced, and nitrogen-13 which is a radioisotope with short half lifetime and neutrons can be produced. And by colliding deuterons as high energy particles19 with the target13 containing nitrogen-14, the nuclear fusion $^{14}N(d,n)^{15}O$ can be induced, and oxygen-15 which is a radioisotope with short half lifetime and neutrons can be produced. Moreover, by colliding deuterons as high energy particles 19 with the target 13 containing neon-20, the nuclear fusion $^{20}Ne(d,alpha)^{18}F$ can be induced, and fluorine-18 which is a radioisotope with short half lifetime and alpha particles can be produced.

6.20. Furthermore, the energy of the particles generated by the irradiation of above-mentioned laser beam 18 such as x-rays and positive ions can be more than threshold energy for nuclear fission, so the nuclear reaction can be easily induced. For example, by using material containing hydrogen as the irradiation target 11 and the materials containing uranium as the target, and by colliding the high-energy protons such as 10 MeV with the target 13, nuclear fission of uranium can be induced.

6.21. Moreover, excitation of nuclei can be induced. By colliding the high-energy ions 19 generated by irradiating the irradiation target 13 with laser beam 18, nuclei inside the target 13 can be excited and nuclear isomer can be produced. Since gamma photons with the same energy are emitted during the transition from excited nuclear isomeric state to stable state, the gamma ray source with line spectral profile can be obtained and can be developed to a gamma-ray laser.

6.22. In this invention, since an ultra-short pulse laser is used to generate high energy particles 19 for inducing nuclear reactions, the size apparatus can be small and the shield can be simple compared with the method of inducing nuclear reactions using nuclear reactors or accelerators. Thus, this invention can supply radioisotopes with low prices. Moreover, nuclear material management can be easier than other methods. Furthermore, radioisotope production can be possible much near to the place where the isotopes are used such as hospitals, and therefore this methods is adequate for production of isotopes with short half lifetime.

6.23. Moreover, the control of nuclear reaction can be easy by this invention because nuclear reactions are induced by irradiation of the laser beam18. Starting and stopping of nuclear reaction can be performed by on and off of laser beam 18. By adjusting focusing intensity and energy of the laser beam 18 the energy of the generated high energy particles 19 can be controlled, and therefore yield of nuclear reactions can be controlled.

6.24. Although above mentioned examples are among the best example, there are many styles for using this invention. For example, although the irradiation target 11 and the target 13 are different and separated in the above mentioned example, the irradiation target 11 and the target 13 can be merged to the same target, and nuclear reaction can be induced with nuclei inside the target irradiated by the laser beam 18. In this case, the region where nuclear reaction is induced can be limited to the small region close to the laser focusing area irradiated by the laser beam 18.

6.25. Moreover, although the high-energy particles are mainly protons or deuterons, in the above mentioned examples, triton can be used as an example, and mixture of these particles can also be used.

6.26. Moreover, the laser beam 18 can be irradiated on to the irradiation target13 repetitively with pulse interval shorter than the half-lifetime of the products by nuclear reactions. Therefore, amount of isotopes with short half-lifetime can be increased by accumulation.

Moreover, although an irradiation target 11 is a thin film, gas jet can be used as a irradiation target 11. For example, super sonic gas jets can be irradiated by the laser beam 18.

7. EFFECTS OF THIS INVENTION

7.1. As mentioned before, the method of inducing nuclear reactions in this invention generates high energy particles by irradiating an irradiation target with a laser beam which can ionize the irradiation target during very short time, and induces nuclear reaction by colliding of these high energy particles with a target. Therefore, this method can induce nuclear reactions easily. Therefore, this method can induce nuclear reactions with lower cost than the case of inducing nuclear reactions using nuclear reactors and accelerators. And management and operation of this apparatus are easier than nuclear reactors and accelerators. Therefore, this method can supply x-ray, electron beam, ion beam and radioisotopes used in diagnostics of large structures such as building and diagnostics in medicine with low price. Moreover this method has advantage in non-use of long life radioisotope and in easier nuclear material management.

7.2. Moreover, Since this apparatus of this invention has a irradiation target, lasers which can ionize the irradiation target and can generate high energy particles and a target containing nuclei which is induced nuclear reaction by the high energy particles, the nuclear reaction can be induced using this simple apparatus. Therefore, radioisotopes and radiation sources are obtained with low cost.

8. SIMPLE DISCRIPTION OF THE DRAWINGS

Fig.1 The flow-chart showing the method of high-energy ion acceleration and for inducing nuclear reactions of this invention.

Fig.2. The schematic diagram of the apparatus for high-energy ion generation and for inducing nuclear reactions in this invention.

Fig.3. The relation between laser intensity and maximum energy of generated ions.

9. DESCRIPTIONS OF SIMBOLS

11. Irradiation target
12. Laser and equipment for laser irradiation
13. Target for nuclear transformations
18. Laser beam
19. High energy particles

Further details of the invention or inventions will become apparent when this specification is read in conjunction with the accompanying appendix

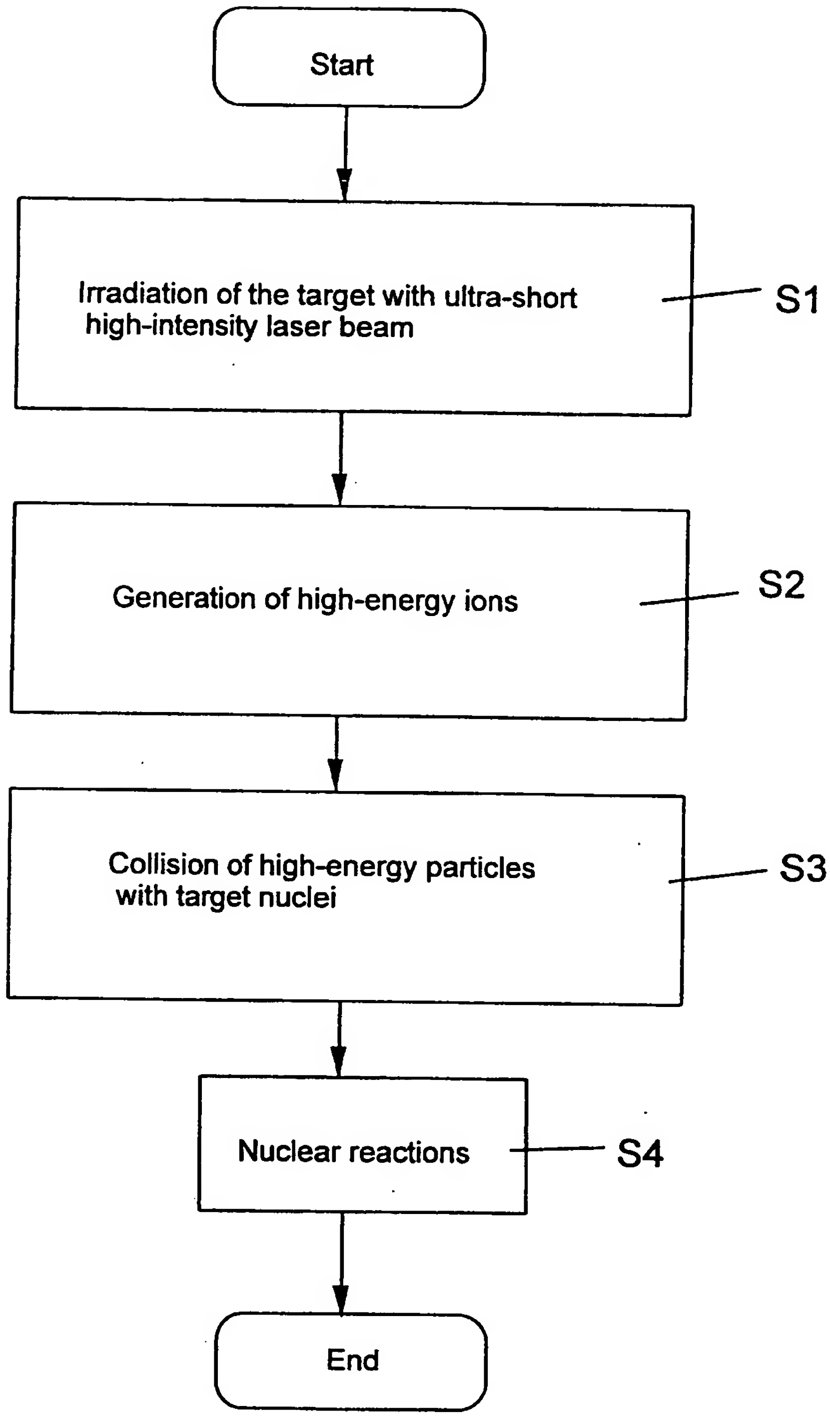


Fig. 1.

Marks Clerk

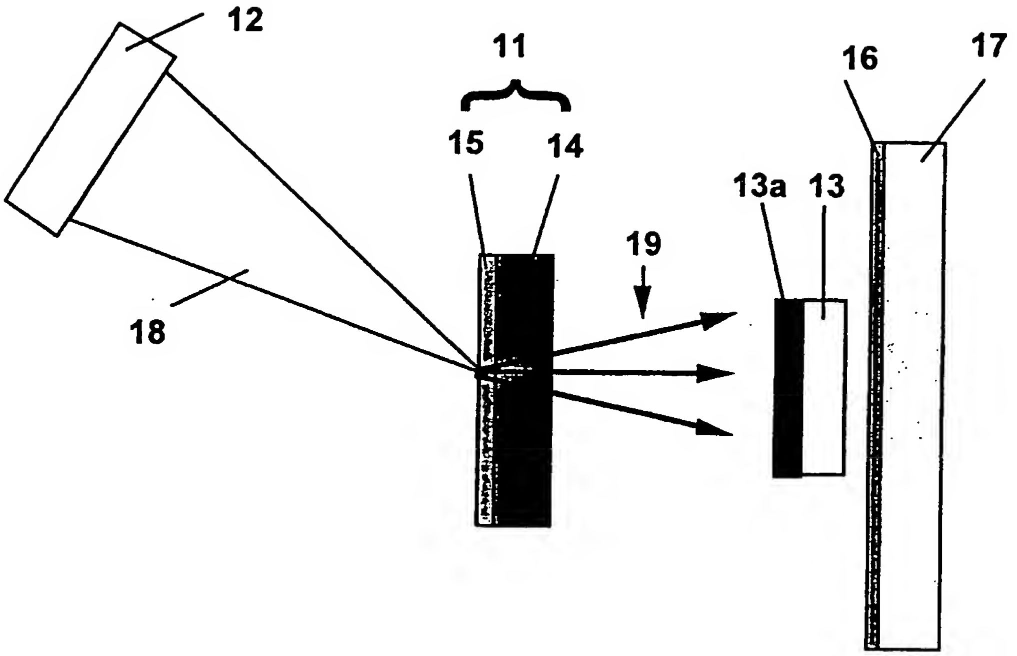


Fig. 2

Marks & Clerk

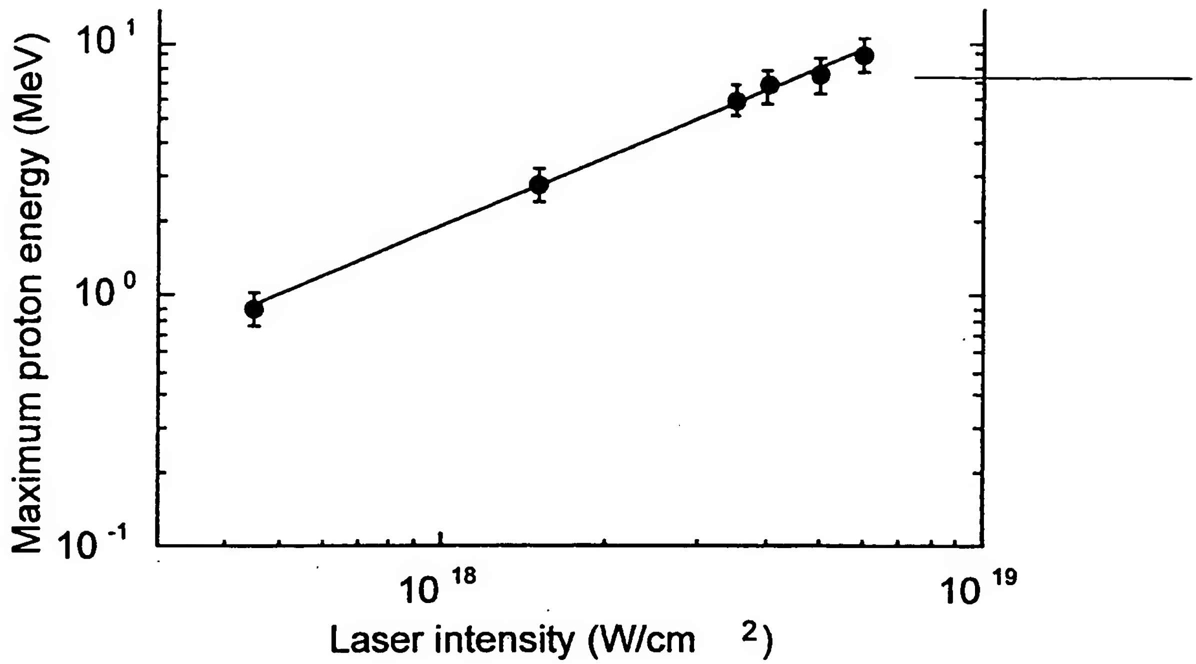
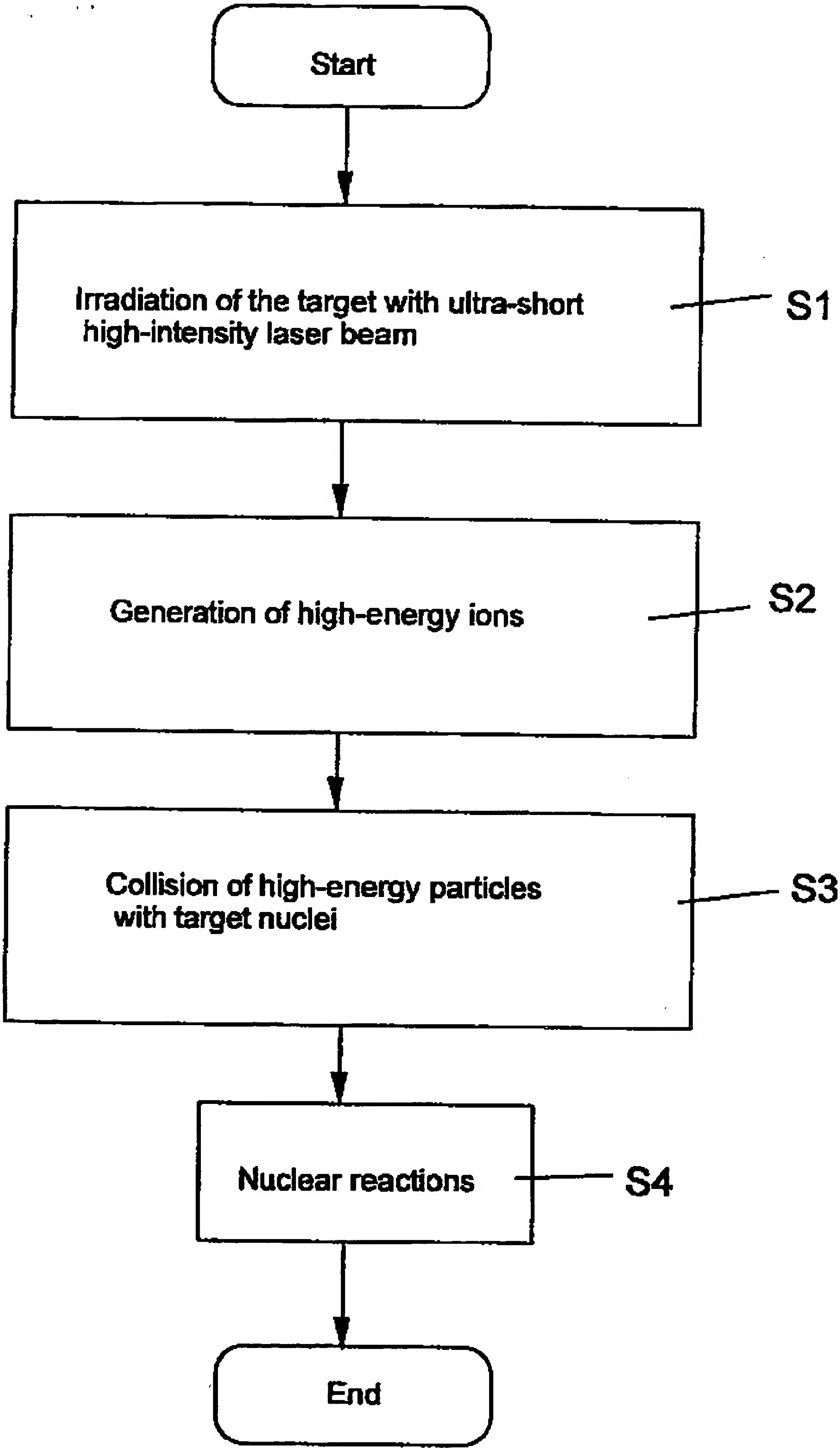


Fig. 3.

Marks & Clerk


Start
Irradiation of the target with ultra-short high-intensity laser beam
S1
Generation of high-energy ions
S2
Collision of high-energy particles with target nuclei
S3
Nuclear reactions
S4
End